The Scientific Requirements of Colour Photography

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The Scientific Requirements of Colour Photography.

'Colour Photography' and 'Photography in Natural Colours' are two distinct methods of arriving at the same end, namely the production of a picture of objects in the same colours as they appear to the eye. It may here be said that any feasible theory of colour vision lends itself to the success of Colour Photography, whilst it requires no theory to take a Photograph in Natural Colours. In the one, scientific knowledge is the characteristic, whilst in the other it is the simple act of light; the one cannot be carried out without a preliminary scientific study, the other is independent of it. It is proposed to deal with 'colour photography' first, and show on what principles it is based. We shall use the theory of colour vision which is *par excellence* the simplest, and that is Young's, a theory which was almost independently discovered by Helmholtz, and which often bears his name together with that of Young. This theory tells us it is only needful to mix three properly selected simple colours in order to produce the sensation of any other known colour. These three colours are red, green, and blue—violet; and not the red, yellow, and blue of pigments, as is still

taught by artists. (We must distinguish between colour sensations and colour.) These colours are selected as being those which cannot be formed by the mixture of any others, whilst a simple yellow is not, as it can be formed by a mixture of red and green; indeed yellow and blue light will, when properly mixed, form white, and not green, as they do if they are pigments.

Experiments made with the pure colours of the spectrum are particularly suggestive, as we are then dealing with colours of the greatest purity. A spectrum being formed, three slits are placed in its length, through which pass red, green, and blue rays respectively. Each of the colours coming through these slits forms on a white screen an image of the front surface of the prism which gives dispersion to the white light that forms a spectrum; and by placing a lens in front of the slits all three images are combined and we have white light. Now any of the slits can be mechanically opened or closed, and by so doing we get different colours. The same effect may be obtained by placing in the track of the rays photographic deposits of different opacities which cut off different amounts of intensity from each colour. By altering the opacities we can produce any colour we desire, and this fact is the underlying principle of colour photography. We might have four slits in the spectrum and obtain the same result, but the fourth colour would be like the fifth wheel to a coach, we should not know what to do with it. We shall therefore confine ourselves to the three colours, red, green, and blue, and consider them as sufficient. Let us for a moment note what the experiments teach us; they teach us that if we take three negatives of a coloured object, using for each

light of proper colour, we ought from their transparencies, when illuminated by the colours of the three visual sensations and when the images are combined, to be able to reproduce to the eye the colour of the object. The desideratum is to produce in each transparency such opacity that the light penetrating through each similar part of the three shall when mixed give the colour of that part. (In future, except occasionally, a 'photograph' will mean the transparency produced from the negative.) Thus if we have a purple to reproduce by superposing the coloured images from three photographs, we shall require partial transparency in the 'blue' photograph, and the same in the 'red' photograph, but opacity in the 'green' photograph, and the mixture will make the necessary purple. The light penetrating through the first two, however, must possess intensities not only to form the mixed colour, but also to give the proper brightness to the mixture. Reflection will show that the coloured light with which the three negatives have to be taken must not be simple colours, but that each should occupy a considerable portion of the spectrum, and that these portions should overlap one another. The three pure colours of the spectrum just shown as proper for mixing to produce complex colours would be useless for the purpose of producing the negatives. We have only to consider what would happen if a spectrum were thrown on the screen and that an endeavour were made to obtain photographs using the light of these three colours alone: the only part of the spectrum that would be photographed in the red light would be one particular monochromatic red on the screen, and so with the green and the blue. When the photo-

graphs were viewed together the spectrum would be represented by three bright lines—evidently a most incorrect representation. If, however, we had a correctly sensitized plate, and took three images of the spectrum, one through an orange, another through a green, and another through a blue medium, each possessing correct absorptive characteristics, we should reproduce it correctly, for then the transmitted colours would overlap one another.

We will, however, first consider what the proper colours should be which should be transmitted through the three transparencies when obtained. We must

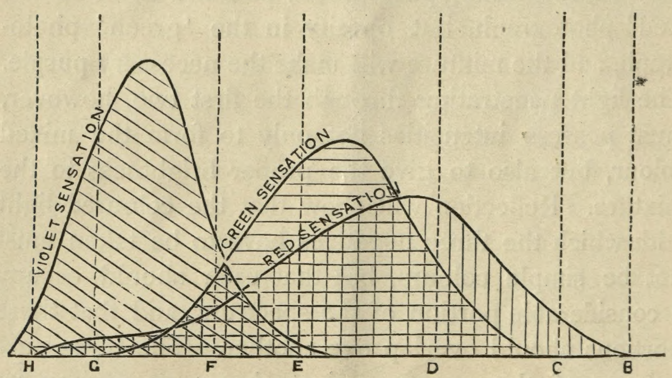


FIG. 1.

select each colour carefully, for we must recollect that there are greens and greens, and reds and reds. If we come to the theory of colour vision, we should find that we had to choose a green which was inclined to blue rather than to yellow. It is outside my present lecture to say how the three sensation curves of the annexed diagram (Fig. 1) are arrived at, but may state that they are shown fairly correctly. When the three sensations

are equally stimulated—that is, when the ordinates are of equal height—we have white light. The height of each ordinate shows the amount of each colour sensation stimulated at each part of the spectrum. Where all the curves overlap, the lowest ordinate of any one shows the amount of white light which is present in any colour, for at that point all the three sensations to the height of that same ordinate combine to make white light, the balance of the higher ordinates giving the colour. It will clear the ideas if a notion is given why three sets of sensations only are necessary to give the sensation of any colour. It is not hard to understand that waves of light vibrating exactly in time with a swinging apparatus (say oscillating molecules) in the eye will increase the amplitude of the swings, but it is less easy to understand why those not in tune will increase the swings, and so give rise to the sensation which these swings cause. If we have two pendulums attached to the same axis, and set one in motion, the other will begin to swing, much or little, the former when it is in tune or nearly so, the latter when it is very different. The figure shows the extent of the

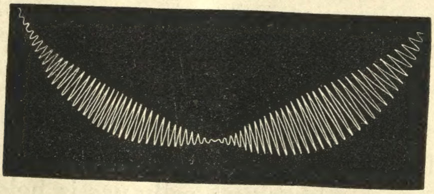


FIG. 2.

oscillations of the latter pendulum when there is not a considerable discord between the two, the registration being effected automatically. It will be seen that motion increases and then diminishes, till there is rest, when it starts again. If we imagine this pendulum to be one

of the three visual pieces of apparatus, we can see that it would be excited by waves not in exact unison with it. Thus we may take it that not only will one set of wave lengths stimulate it, but others on each side; and further, that two or three of the apparatus may be each stimulated by the same wave motion. Thus it is we may get the three sensation waves overlapping each other as shown in the previous diagram (Fig. 1). The same experiment also demonstrates why it is a sensitive salt of silver is affected by wave lengths which are very far from being in tune with the swing of its molecules, a fact which at first sight may be otherwise difficult to understand.

The purest green sensation, that is, green unmixed with any sensation except white, is found in that part of the spectrum where the red and blue curves cut one another (see Fig. 1), for at that point white alone is present with green sensation, but the proportion of white to green is so large that the colour mixtures made with it would be pale. If some other green much less diluted with white, such as that nearer the yellow green, were chosen, the mixtures would be less pale but perhaps not quite so accurate in hue since they would contain a larger proportion of red than they should do. For this reason it is well to choose a green somewhere about E, which is not too red, and in which the white light existing is small.

The red we should theoretically use is below the red lithium line, for there we have but one simple sensation, but it is very feebly stimulated; so again in practice we depart from what we should choose in theory, and select a red near C, which is fairly bright, although the red sensation is slightly contaminated with green. Blue

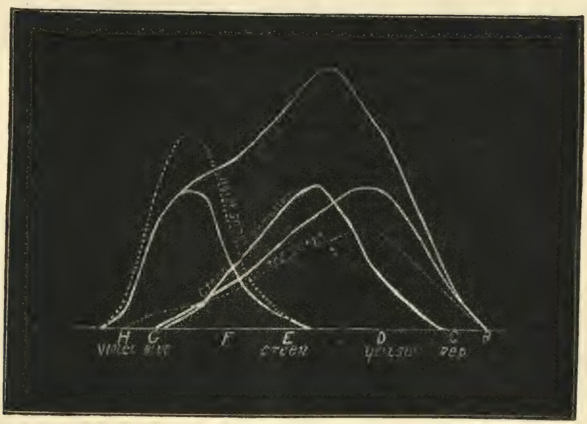
is at all times of feeble luminosity, but as that near the blue lithium line is strongest and fairly pure it is selected.

Now it is manifest that we cannot use spectrum colours for illuminating the photographs, but we can select transparent dyes of some kind which approximately match them in hue, and owing to the kindness of Mr. Ives we have before us the three colours that he uses for the purpose. By an arrangement of the apparatus we can see on the screen that they very closely match in hue the chosen spectrum colours, and further, on looking at the portions of the spectrum which they transmit we find that they are small, and scarcely overlap one another. These are the colours for illuminating the three transparencies which may be used practically. If they were absolutely monochromatic colours they would be still better.

It may be useful before proceeding to our next step to show what difference there is in the three transparencies before the coloured images formed by them are combined, to produce the compound image which gives the colour of the object. The patch of coloured light that is produced on the screen is simply an image of the face of the prism, produced by the simple rays passing through the slit or by a recombination of the rays passing through more than one. If a coloured picture, which may be merely a pattern of coloured glasses, be placed close to the face of the prism, its image is thrown upon the screen, when the whole of the spectrum is recombined. The white light falling on its different parts is coloured by its passage through the glasses, and these different colours are decomposed by the prism itself, and again recombined by the lens

in front, and thus a true coloured image of the object is formed on the screen. We can withdraw the picture, and by placing a slit in each of the three standard colours of the spectrum, we can by their mixture reproduce white light. On replacing the coloured pattern against the surface of the prism, its coloured image reappears, and is almost identical with the image formed by the recombination of the whole spectrum. By removing the one large lens, which combines the whole spectrum, and replacing it by three portions of lenses of equal foci one in front of each of the three slits respectively, we form three monochromatic images side by side, from which the image of mixed colours is built up. It appears to me that this is a good illustration of the process adopted, but it is only an illustration, for had it happened that one of the coloured glasses transmitted colour which was entirely confined to a region of the spectrum which lay between two of the slits, it would have shown as black. The colour screens used by Mr. Ives for viewing his three photographs have already been brought to notice, but I will now show you some others. We can have a disc made up of three sectors of gelatine, a red, a green, and a blue, and so arranged that the rays which pass through them when mixed in the eye by its rotation approximately give white light. The disc is now rotated in the beam of light which issues from the lamp and passes through the apparatus. The colours of the glasses on the screen are apparently unchanged. Stopping the rotation and allowing the different colours to stay in path of the beam of light, we see that we have three differently coloured images. That these colours are by no means pure colours, their absorption spectra will show.

We must now consider the question of the production of suitable transparencies for the purpose. The problem must be now stated explicitly. It must be recollected that a photographic plate knows nothing of colour *qua* colour; all it registers is the effect of vibrations, and their effect is to produce more or less opacity at the different parts of a negative when the plate is developed, which opacity is reversed in the transparency. It will be evident that what we have to try and attain is that in a photograph of the spectrum the three negatives shall have the same ratio of opacity as the ordinates of the three colour sensations at the different parts.



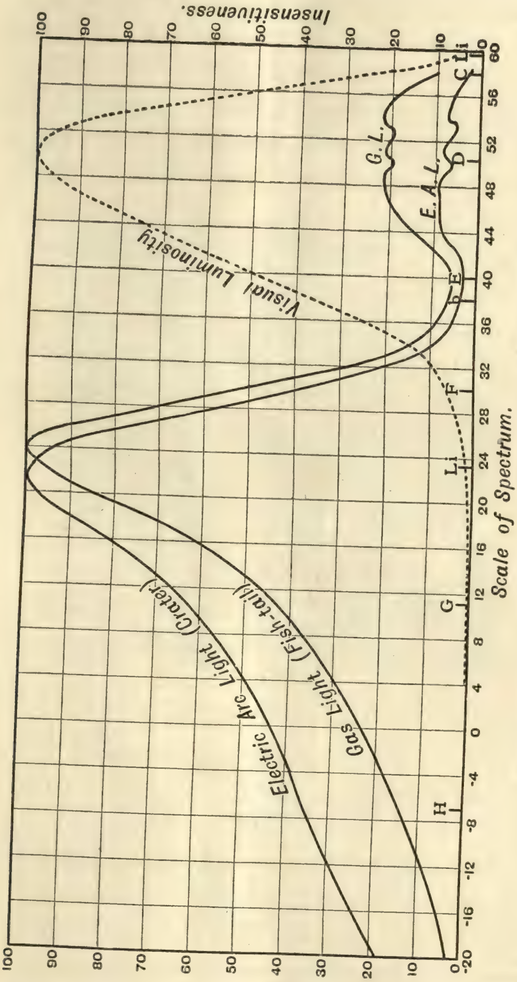
Three sensation curves combined together.

Fig. 3.

If we can obtain three such negatives of the spectrum, the light passing through the three transparencies taken from them, if viewed of the appropriate colour, will, when the images are superposed, give a picture of the spectrum. It is a point to remember that the opacities of the transparencies should not indicate the *luminosities* of the different parts of the spectrum; each transparency

should have some one place free from deposit, and should graduate down to nearly complete opacity. *The luminosity of the different parts of the spectrum is secured by regulating the luminosities of the three viewing colours.* If the spectrum can be completely and correctly reproduced visually, the colours in any object, no matter how mixed they are, will be reproduced with the greatest exactitude. Unfortunately there is no photographic plate extant which gives a curve of opacity for the spectrum which is similar to the three sensation curves combined, such as is shown in the diagram (Fig. 3). The diagrams of opacity of the spectrum image on different plates show that not one of them fulfils the condition. The plate which most nearly answers to it is the Cadett spectrum plate, but that is not altogether satisfactory, as there is such a preponderance of blue sensitiveness, but this can be partially eliminated as we shall see. The ordinary plate is the worst; it is practically insensitive below the yellow, and hence with such a plate the 'red' photograph would show no image, so that with it a correctly coloured image, of which red formed a part, could not be reproduced. With the others there is more or less sensitiveness to the yellow and orange, and with these we can work for reasons that will shortly be given. In a theoretically perfect plate, if we take into account the extent of the spectrum covered by the colour sensations, the screen should admit to the red negative red, yellow, and orange, to the green negative yellow, green, and blue green, and to the violet, blue, and also green blue. With such imperfect plates as are available we evidently must compromise, since theoretical perfection is unattainable. Thus, an eosine dyed plate is very

insensitive to one part of the green, and also to the red; we therefore have to choose a coloured 'taking'

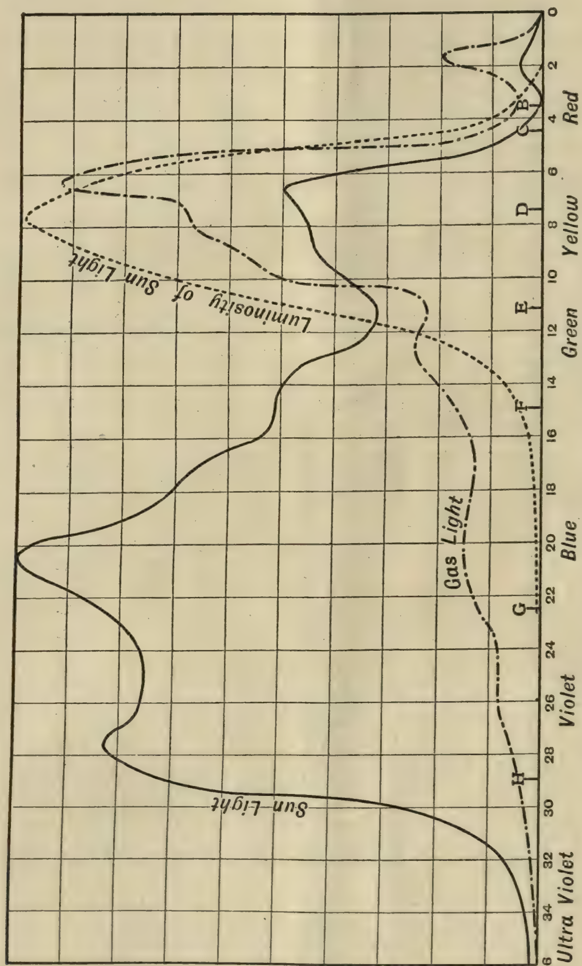


Sensitiveness to the spectrum of a Lumière red-yellow plate.

FIG. 4.

screen (that is a coloured screen placed in front of the lens of the camera or close to the plate), which shall fairly cover the range of the red sensation excited

by any coloured object, after taking the above defect into account. For the red negative the yellow then

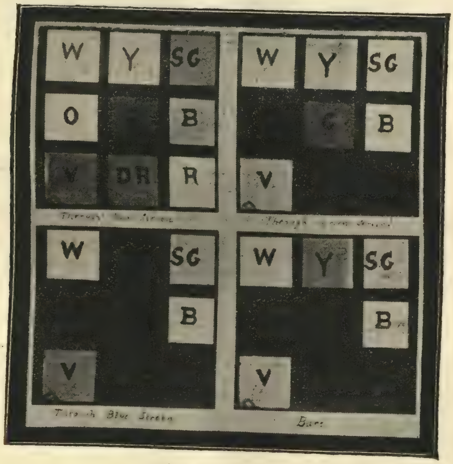


Sensitiveness to the spectrum of a Cadett's 'spectrum' plate.

Fig. 5.

becomes all important, and for the green the colours on each side of the green gap have to be utilized. Thus a screen, which theoretically should be a deep

orange, has to be replaced by a yellow one, and the green by one somewhat differing from the theoretical colour. Broadly speaking, every plate which is sensitive into the orange can be used for this three-colour work by increasing the range of the spectrum light admitted through the taking screen. It is quite evident that these alterations are compromises. If we had an object radiating nothing but pure spectrum red,



W is white glass.
Y is yellow glass.
SG is signal green glass.
O is orange green glass.
G is dark green glass.
B is light blue glass.
V is violet (manganese) glass.
DR is dark red glass.
R is lighter red glass.

FIG. 6.

plates insensitive to the red would show it as black. Generally speaking, however, no object in nature is coloured with mono-chromatic light; the reds contain yellow, the greens yellow and blue, and blues, blue and green, and thus by altering the hue of the taking screen we can reproduce approximately in a negative the density which, when made into a transparency, will

allow the same amount of light to pass as would have passed had it been taken with a perfect plate, using a theoretically perfect colour screen.

It may interest you to see the three prints from negatives of the coloured glasses taken through the above-mentioned screens on an eosine dyed plate. A fourth print has been added from a negative in which no screen was used, and it will be found to be very similar to that taken through the blue screen. If the images of the three prints were coloured of equally bright red, green, and blue, they would when visually superposed give an image of the glasses in correct colours.

We have further to arrange that the exposures to the plate through each screen shall be the same and yet that each shall be sufficient to give a properly exposed negative on development. Even in the most effective plate the blue end of the spectrum is overpoweringly strong compared with the effect of the other parts of the spectrum. As it is our aim to make the exposures of the three negatives the same, it is evident that the time of exposure for all three negatives must be that which would be given to the negative taken in the colour to which the plate was most insensitive. How is this increase of exposure to be effected?

Mr. Ives, who has been the pioneer in the application of exact science to Colour Photography, takes his three negatives on the same plate at the same time with but one lens. The light transmitted by the blue screen comes through a very small aperture, and after reflexion from transparent mirrors a very feeble blue image falls in its proper place upon the plate. The final outcome of this plan is, that with this diminution for the blue,

and a less severe one based on the same principles for the green, the red, green, and blue negatives can be taken at the same time and with the same exposure. Mr. Ives has kindly lent me a transparency of the three negatives thus taken, each backed with the proper viewing colour. This transparency tells its own tale. He has also kindly sent for inspection a Kromoscope, which is the instrument in which such a transparency is viewed and in which the three coloured images are combined.

I must now refer to another very beautiful development of photography in colours, due to Dr. Joly of Trinity College, Dublin. He has worked on identically the same lines as Mr. Ives, so far as theory is concerned. He has adopted the three-colour sensation theory, and uses as colours with which to view the object the same three colours. The important difference between the two methods is, that in Joly's method only one negative is required. His method is essentially one which is founded on what may be termed a happy imperfection of the eye. The human eye is unable, without aid, to separate points which lie very close to one another. Black lines on a white surface which are very close to one another blend with the white surface and give to it the appearance of grey. Indeed the engraver's art is founded on this blending. Line engravings, viewed at a little distance, show this admirably. At a distance an engraving and a properly taken photograph in half-tone from the same picture cannot be distinguished. Again, if we examine some kinds of highly finished water-colour drawings or miniatures, and examine them at a little distance, we find perhaps delicate greys existing. If, however,

examined with a glass, these greys break up into minute stippling or dots of colour. The eye blends the colours together and we have the grey produced.

Joly rules on glass plates transparent lines of red, blue, and green, $\frac{1}{200}$ of an inch in breadth, in succession, and touching one another, and at a very little distance the screen when looked through appears to be a delicate grey. Of course the lines have to be made of such a depth of colour that the mixture of the three colours,

Red Green Blue

FIG. 7.

by a rotating colour disk, would appear a degraded white; and as the red, green, and blue would have to be of equal angles on the disk (the ruled lines being of equal breadth), it will be seen that the alteration in hue can only be effected by altering the depths of the colours. The absorption spectra of these three colours, as given on a Cadett's spectrum plate, is shown in Fig. 7. For a taking screen a surface, ruled with lines of exactly the same breadth ($\frac{1}{200}$ of an inch), but in three

colours slightly different from those in which the viewing screen is ruled, had to be employed. As before, the red gives place to an orange and the green is altered in hue, whilst the blue may be the same as the viewing screen. The absorption spectra of the three colours used for obtaining the negative is shown in the accompanying diagram (Fig. 8), the plate

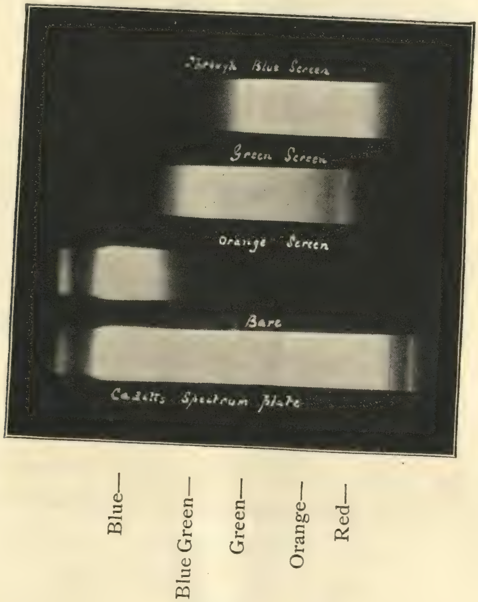


FIG. 8.

used being a Cadett's spectrum plate. When a negative has to be taken, all that is required is to place such a screen in contact with the plate in the camera and to use some medium in front of the lens which shall cut off the ultra-violet light and dim the violet and the blue which is to the eye invisible. This done, the ordinary process of photography is adopted. Dr. Joly uses Cadett's spectrum plates, which, as we saw, are

sensitive to the whole of the spectrum. Now what is the effect of taking a negative through such a screen as this? It is this: beneath the blue lines, $\frac{1}{200}$ of an inch broad, the negative has been taken with blue light, beneath the green lines with green light, and beneath the orange lines with orange light. When the viewing screen, made up of lines as before mentioned, is placed behind the transparency in such a way that the lines taken through the blue are covered by the blue, through the green by the green, and through the orange by the red, then we have a fairly perfect coloured representation of the object. As before said, this is solely due to the eye blending the colours one with the other.

Now these processes, which are based on purely scientific methods, are available only for photographs viewed by transmitted light; but there is a modification, on a slightly different principle, which renders it possible to make it applicable to coloured prints. The colours in the processes so far described are not those of pigments mixed together, but are due to the light coming through each of the pigments separately and then mixed. The question is whether we can get similar results by allowing light to traverse superimposed layers of pigments of different colours. The light coming through a piece of yellow glass placed behind or in front of a piece of blue glass (the order is immaterial) is green, and the light passed through a yellow and a purple glass is red. By superimposing pigments of different colours, the colour that will be transmitted or reflected is that which will pass through two or more of them. Suppose, then, that we print by the carbon process in colourless gelatine Ives' three negatives, and dye that one taken for the red viewing screen with blue green, that for the

green with purple, and that for the blue with yellow, and place them one over the other, we shall find that we have a fair representation of the object in colour. It will be noticed that the dyes are the exact complementaries to the colours of the viewing screen. Following the matter out, we should find that on placing the three films over each other and viewing them by transmitted light, for a red we should have white light passing through purple and yellow or vice versa, it matters not in what order. Purple is red + blue; yellow is red + green. The blue in the purple cannot pass through the yellow, nor can the green in the yellow pass through the purple, but the red can pass through; we then see that the print will show red where it ought to be: and so with the pure green and the pure blue, we should get these colours shown where they ought to be. Let us take the question of a yellow colour. This colour is made up of green and red sensations; in the red and green negatives this would be shown by half opacities, whilst in the blue negative it would be shown as transparent. There would be a semi-opacity in the blue-green print from the red negative, and a semi-opacity in the purple print, but the yellow print would keep its own full tone; the blue in the purple and the blue-green would be entirely stopped by the yellow, but the red and the green would not be wholly stopped by the blue green and purple—they would be half transmitted, and these would form a yellow, which would not be stopped by the yellow film. It follows, then, that a yellow would be shown as such from colour of the yellow print from the blue negative, and so we might trace any other colour. Instead of using films, such as Mr. Ives does in his modified process, we may

use transparent inks to produce pictures by three printings. For colour printing the use of colours complementary to those of the viewing screens is an advantage, because the most brilliant pigment we can use is yellow.

The next process that I shall describe is the oldest, and that is the production of colour by the action of light itself. The question is often asked, 'When are we going to have photographs in natural colours?' The answer to give is that they were produced almost as soon as photography was discovered. Becquerel found that if instead of iodizing a plate he chlorinized it, and then exposed it to white light, it gradually assumed a violet tint, and in this state if exposed to the spectrum all the colours of such spectrum were impressed on it. What these colours were due to was, for a long time, a mystery, but a good many years ago I was able to indicate that at the red end of the spectrum the lavender-coloured material took up oxygen, whilst at the violet end the sub-chloride became further reduced; thus we had big molecules formed by the addition of the oxygen which vibrated slower, whilst the abstraction of chlorine gave smaller ones. Recently it has been shown that part of the result is due to the effect of stationary waves to which I shall allude presently. Years ago I was able to produce the same effect on collodionized glass plates containing chloride of silver; these, when exposed to white light, blackened, and when exposed to the spectrum took all its colours which, when viewed by reflected light and by transmitted light, were found to be of the same hue. The stationary wave theory will be found not to be tenable in this case since the colour is produced by transmission and also by reflexion.

One failing however all these coloured photographs had, and that was that they rapidly faded in white light. They were true pigments but of a most unstable nature, and they were bound to fade from the very way in which they were produced. Photography in natural colours, according to my definition, is photography in pigments. Any one can produce a photograph showing colour: let a piece of albumenized paper be darkened in the light and then placed in the spectrum. It will be found that a blue and a red are impressed in the right positions together with a suspicion of green; but, alas, they fade like the others. Lord Rayleigh was the first to point out that the colour in photographs to show by reflexion was physically possible by the formation of stationary waves. Suppose we tie a rope to a staple in a wall and hold it say 10 or 12 feet off, we can send periodic impulses along that rope in the shape of waves, reaching the tied end of the rope. When they arrive there they will return back to the hand and compound with those waves which are travelling from the hand. There will be points of no motion at intervals along the rope. If a ray of mono-chromatic light passes to a reflecting surface and back again, something of the same kind will take place, and we shall have stationary waves of light, if that be a good term to call them. It matters not whether the light pass through a transparent body, in which the molecules are in vibration or not, stationary waves will occur, and if the vibrations of the molecules be in tune with the rates of vibration of these waves, they will be capable, as they are in ordinary photography, of being shaken asunder, a photographic action will take place between the nodes, and we shall have spaces of action interspersed between places of no

action. If a beam of white light be sent through these shaken-up molecules they will select the ray which is suitable—that is, the same ray that produced them, and reflect back only that colour. One can understand this perfectly, but we have to deal with another phenomenon discovered by Lippmann, and that is that a sensitive salt can be used and be developed and still the colour will be reflected. It is an interesting fact that if one of the developed 'noded' gelatine films be moistened, the colour disappears by reflexion; this is simply due to the fact that the gelatine swells and the distance apart of the nodes alters. When the film is dried they revert to their original condition. There is only one main direction in which the true colours are reflected, there being some alteration in hue if not so viewed.

It is a most interesting fact that photographs by this plan can be produced to show not only the simple colours of the spectrum, but also mixed colours. Let it be remembered that the colour is produced by the abstraction of colours. The photograph when looked at in the usual way appears like any ordinary negative, and it is only when examined with the light falling on it at one particular direction that the colour appears. Evidently these photographs do not fall under my definition of what is photography in natural colours. There have been recently two processes brought forward for producing coloured prints direct from a negative Chassagne's and Benetto's. About Chassagne's we know all that the patent can tell us. I saw the process worked, and can say that it did produce prints which resembled the original objects. They were produced by roughly brushing on the print three dyes, a blue, a green, and

a red, in the order given, mixed with an albumen solution. The results were good, but near inspection of a portrait so coloured indicated that the negative from which the objects were produced had but little if anything to do with it. The specification for the patent makes no mention of any particular form of negative, so I am led to believe that my speculation was right. As to Benetto's process, the results I have seen are very good, but as to its details I know nothing. It is a secret at the present time.